

THE OPTIMAL CARPOOL PLANNING, BASED ON IOS PLATFORM

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ABSTRACT

The rapid development of technology has aggravated global warming and air pollution, particularly in metropolises, with high population density. Urban overpopulation has also caused serious traffic problems. The area around the Neihu Technology Park in Taipei City, for example, has long suffered from traffic congestion, during peak hours. To address such urban traffic issues, innovative transportation services are as important as modification, in design of major roads. Taipei City Government, therefore, intends to implement traffic control in favor of high-occupancy vehicles and promote taxi-based carpools so as to alleviate traffic jams. In light of the above, this study focuses on taxi sharing services and on how to make the services more convenient and more flexible by using a mobile application program (or APP for short) supported by the IOS platform. Based on each passengers boarding and alighting locations, which are input into the APP, the APP performs passenger matching and route planning via cloud computing and the NSGA-II algorithm, in order for a taxi driver to view passenger information and the planned shortest route, and for each passenger to know the driver's information, the route, the vehicle departure time, the estimated arrival time, the fee, and so on. Working on mutual trust, this system features transparency, real-time operation, and traceable riding information to help increase the use of carpools and add more value to vehicle sharing services.

KEYWORDS: Taxi Sharing, IOS, Cloud Computing, NSGA-II Algorithm & Route Planning

Received: Sep 18, 2017; **Accepted:** Oct 08, 2017; **Published:** Oct 28, 2017; **Paper Id.:** IJCNWMCDEC20171

INTRODUCTION

Background and Motivation of the Study

Global warming and air pollution are exacerbated by the rapid development of technology, especially in highly populated urban areas. According to data published by the Directorate- General of Budget, Accounting and Statistics (DGBAS) of the Republic of China, Taiwan ranks second in the world in population density and gasoline consumption per capita while having the highest vehicle density. One major source of air pollution in Taiwan, therefore, is the pollutants emitted from cars and motorcycles, and the reduction of vehicle exhaust, a critical step to prevent and control environmental pollution. Currently, vehicle occupancy is low in urban areas, resulting in not only traffic congestion but also severe air pollution. If carpools can be effectively promoted, with properly planned routes, and with passengers' needs taken into consideration, more and more people will be willing to participate, thus reducing the number of cars on the road and mitigating air pollution.

Early vehicle sharing services in Taiwan were carried out as follows. Vehicle sharing needs were typically posted on bulletin boards of a local area, community, or company, and those who were willing to share a vehicle with others registered themselves by phone and made arrangements for the pickup time and places. Nowadays, the rapid advancement of smart phones and tablet computers, together with the rise of intelligent transportation

systems, has made possible a vehicle sharing system that incorporates such technologies as vehicle positioning, wireless communication, and dynamic real-time matching, and that allows only a member of the system to log in to the system through a mobile phone as a way to solve security problems involving personal riding habits and privacy. Moreover, in place of the traditional posts, automatic matching mechanisms have emerged to match carpool passengers by means of web-based algorithms, which greatly enhance the flexibility and convenience of vehicle sharing services.

To encourage more people to use vehicle sharing services, it is important to satisfy passengers' needs and provide door-to-door services through a convenient and easy-to-use system. The system should be able to eliminate the conventional inconveniences of matching passengers by the passengers themselves and perform automatic matching to not only reduce the time required to look for a vehicle and other passengers, but also screen vehicles and passengers according to users' needs. Furthermore, the system should allow a user to check out routes, vehicle information, and so on, with a view to reducing the user's sense of insecurity during a shared ride

Objectives of the Study

This study aims to establish a mathematical model for the problem stated above and to develop an algorithm for solving the problem, taking into account the needs of urban passengers in particular. Given the emphasis an urban passenger tends to place on time, two major factors that influence an urban inhabitant's willingness to use a vehicle sharing system are the thoughtfulness of the system and the ride time. While sharing vehicles allows passengers' travel needs to be advantageously satisfied with the smallest number of vehicles and traffic jams to be relieved at the same time, travel time must also be shortened to add to the appeal and value of vehicle sharing. In addition, despite the advantages of vehicle sharing, willingness to share a vehicle with others may be weakened by difficulties in matching passengers' pickup time and locations, in distributing fees among passengers, and in discounting the fees. It is hence imperative to know the factors affecting the demand for vehicle sharing services and to provide an efficient and user-friendly system for assisting, and ensuring long-term operation of, such services. This study begins by establishing a mathematical model based on urban passengers' vehicle sharing demands. Then, a multi-objective genetic algorithm is applied for solutions. An APP that integrates both vehicle information and passenger information is thus developed. After a driver inputs a starting location, a destination, and a departure time, and by connecting to a database and cloud computing, the APP matches passengers wishing to share the vehicle, screening out passengers in the database whose demands cannot be satisfied by the current conditions. Then, the APP plans an optimal route and sends the route to the driver's and the matched passengers' mobile devices as an iOS map. The entire system is sound and stable and helps increase the public's willingness to share vehicles so that the number of vehicles on the road can be reduced to effectively prevent traffic jams.

The Objectives of this Study are

- To apply system development techniques to the creation of an iOS-based carpool matching service system, in response to the government's initiative to implement traffic control, in favor of high-occupancy vehicles and to promote carpools in Neihu Technology Park, with a view to providing passengers, with a new mode of vehicle sharing services; and
- To connect an APP to a database through the system platform; to match passengers by computing with a heuristic algorithm to shorten passengers' waiting time; and to perform proper taxi planning in order to pick up and transport all the passengers to their destinations with the smallest number of vehicles and the shortest total travel

time, to prevent traffic congestion associated with an excessive number of vehicles, and to arrive at reasonable fees for the benefit of both drivers and passengers.

To provide passengers with access to vehicle sharing information such as taxi drivers' information, the identification number of the vehicle to be shared, the passengers to share the vehicle with, the fee, and the planned route, allowing passengers to have peace of mind while enjoying the convenient vehicle sharing services.

LITERATURE REVIEW

Discussion on Literature Involving Vehicle Routing Problems with a Time Window

After years of development, vehicle routing problems (VRP) have evolved into many variations, a notable example of which is vehicle routing problems with a time window (VRPTW). The concept of time windows is important to researches on VRP because in actual route planning, those who share a vehicle have different ride times respectively. While most vehicle routing problems without time window constraints have been properly studied, VRP variations with such constraints are still faced with challenges (Miranda and Conceição, 2016). The random travel time in VRPTW is more difficult to determine than that in vehicle routing problems without a time window. Depending on the strictness of temporal constraints, time windows can be divided into hard time windows and soft ones. A hard time window requires vehicle arrival within a specified range of time and does not allow a vehicle to be late, for the services of the vehicle will be denied if the vehicle arrives late. A soft time window, on the other hand, allows a late arrival to be dealt with via waiting or a fine. Difficulties arise when the probability distribution of customer arrival time varies under the constraint of a hard time window (Gendreau, Jabali, and Rei, 2014).

With the changes of industry types, VRPTW has been more widely applied and discussed than before, including those involving security patrol services, mail delivery, school bus, and so on (Desaulniers *et al.*, 2014). To solve such problems effectively, Zhang *et al.* (2016) established three models, with estimated problem-solving time derived from different perspectives and random demands. The first objective is to look for the delivery route of the lowest expected total cost. The second objective is to maximize the probability of on-time delivery to all customers. The third objective is to lower the expected total cost while ensuring that the time of delivery to each customer is within a specified time range. The authors proposed and discussed two methods for solving problems with the three models. The first method is preventive purchase, and the second is to detour to a warehouse in order to load a vehicle. According to the authors' study, the first method yields better solutions than the second does.

It can be known from the above that recent years have seen more and more emphasis placed on time window constraints. With time being at a premium nowadays, it is highly desirable for delivery companies to reach each destination rapidly and for customers to receive their purchased products as soon as possible. The ultimate goal is not only to shorten travel distances and save energy, but also to contribute to sustainable development of the environment.

Multi-Objective Optimization

In real-world applications, optimization with a single objective is insufficient in dealing with decision problems because the optimal solution tends to be compromised in quality, if not rendered infeasible, by any disturbance or change of the input data. Solving a shortest-path problem, for example, requires a balance between time and cost, too, and the objective functions involved are typically conflicting. Single-objective optimization is different from multi-objective optimization mainly in that the former is unable to consider several conflicting objectives at the same time. This explains

why most problems in the real world need to be solved with multiple objectives in mind and, under the condition of meeting multiple constraints, will have a Pareto-optimal solution as a non-dominated solution. A multi-objective optimization problem involves a plurality of objective functions to be minimized or maximized. Mathematically, multi-objective optimization can be expressed by the following equations and inequalities (Marko Kovačević *et al.*, 2014), in which: equation 2.1 denotes a multi-objective optimization problem, with k objective functions; $g_j(x)$ in inequality 2.2 is a constraint function of inequality; $h_i(x)$ in equation 2.3 is a constraint function of equality; and x_L and x_U in inequality 2.4 are the lower limit and the upper limit of the variable, respectively.

$$\text{Minimize } f(x) = \{f_1(x), f_2(x), \dots, f_k(x)\} \quad (2.1)$$

$$\text{s.t. } g_j(x) \leq 0, j = 1, 2, \dots, J \quad (2.2)$$

$$h_i(x) = 0, i = 1, 2, \dots, I \quad (2.3)$$

$$x_L \leq x \leq x_U \quad (2.4)$$

As multi-objective algorithms can better simulate real-world problems, than their single-objective counterparts, more and more scholars have begun devoting themselves to design and research in the former field. Schaffer is generally recognized as the first scholar in the 1980s to propose the concept of the Multi-Objective Optimization Evolutionary Algorithm (MOEA). Schaffer's method is called the Vector-Evaluated Genetic Algorithm (VEGA), which adds a selection mechanism to the conventional GA. VEGA, however, is flawed in many ways, the most important one of which is that the solution obtained does not stay in an acceptable range and is not particularly prominent for any of the objective functions, even if the solution is greater than the common average (D. Martín *et al.*, 2014). Following VEGA, more multi-objective algorithms were proposed. Deb *et al.* (2002) put forward the improved Non-Dominated Sorting Genetic Algorithm-II (NSGA-II), which uses such steps as population sorting, crowding distance calculation, and the elitism strategy to overcome slow convergence and the problem of being trapped in a local solution. Jensen (2003) reduces the complexity of NSGA-II, by means of a different sorting process and a different data structure. Yijie and Gongzhang (2008), proposed three modes of crossover operators, namely the maximum distance, the maximum-minimum distance, and the neighboring maximum distance. Bo Feng *et al.* (2010) improved NSGA-II, by sorting and by using a particular chromosome selection method. Reiter and Gutjahr (2012), incorporated NSGA-II with GA to solve dual-objective vehicle routing problems, with capacity limitation, and the resulting Pareto solution set is somewhat enhanced in comparison with those obtainable by the conventional approaches. Taking the foregoing into account, this study uses the number of vehicles and time, as factors in shared-vehicle route planning and solves routing problems via NSGA-II, which according to the above is highly applicable, and is efficient in finding solutions, to multi-objective problems.

MODEL ESTABLISHMENT

Definition and Hypotheses of the Problem to be Solved

The numbers of cars and motorcycles keep increasing in Taiwan, whose vehicle density has long been one of the highest in the world. The urban areas in particular, such as the area around the Neihu Technology Park in Taipei City, are notorious for traffic jams during peak hours. Apart from modifying the plans and designs of major roads, it is important to find novel transportation service modes, as solutions to urban traffic problems. In this study, therefore, a vehicle sharing service system, based on open vehicle routing problems is established by incorporating the use of handheld mobile devices by taxis drivers and passengers, in order to provide multipoint-to-multipoint services from door to door. Passengers are

required to input their boarding locations and alighting locations in advance; the system will determine the corresponding longitudes and latitudes through the Global Positioning System (GPS). Then, the system plans routes by distributing vehicles and matching passengers. Both drivers and passengers can view the route planning results and other related information via an APP, so that both parties benefit from the convenient services.

Limitations and Hypotheses of this Study are as Follows

- The coordinates of the starting location of each taxi are known.
- The quantity of passenger demands, (i.e., the number of passenger demand points) is known, and so are the coordinates of all the boarding locations and alighting locations.
- Vehicles are divided into large vehicles and small ones, both having occupancy limitations.
- Passengers who are matched by the system to take the same vehicle are not allowed to deny the matching result for any reason.
- All the vehicles run at the same speed and basically follow the upper speed limit of each road, as specified in the map information.
- No vehicles need to return to their respective starting locations after completing the services, so only one-way travels are planned.
- It is assumed that there is no upper limit on the number of vehicles available for services.

Mathematical Model

The route planning problems to be solved by the taxi-sharing passenger matching service system in this study are similar to open routing problems. Objective functions for achieving the smallest number of vehicles and the shortest total time are used to establish the mathematical model of this study. All the symbols in the model and their definitions are listed in Table 1.

Table 1: Symbol Definition

Symbol		Definition
Parameter		Network Diagram, $G = (V, A)$
	N	A set of nodes, $D = \{d_0, d_1, \dots, d_n\}$, in which node d_0 is the starting location
	A	A set of nodal lines, $A = \{(v_i, v_j): v_0, v_1 \in N, i \neq j, j \neq 0\}$
	V	A set of taxis, $V = \{1, 2, \dots, v\}$
	K	$K \in \{1, \dots, m\}$, denoting a set of m different vehicles types
	k	$k \in K$, denoting vehicle type k
	Q_k	Denoting the upper occupancy limit of a taxi of vehicle type k
	CQ_i	Denoting the number of passengers to share a vehicle with that is acceptable to the i^{th} passenger
	q_i	Indicating that passenger demand point i has a non-negative demand
	n	Denoting the number of passenger demand points
	t_{ij}^v	Denoting the time it takes for the v^{th} taxi to travel from node i to node j
	s_i^v	Denoting the time at which the v^{th} taxi begins services at node i
	L_i	Denoting the lower limit of the time window at node i
	U_i	Denoting the upper limit of the time window at node i
	a_i^v	Denoting the time at which the v^{th} taxi arrives at node i

Table 1: Contd.,		
	b_i^v	Denoting the time at which the v^{th} taxi departs from node i
Decision variables	x_{ijk}^v	$\begin{cases} 1, \text{the } v^{\text{th}} \text{ taxi of vehicle type } k \text{ travels from node } i \text{ to node } j \\ 0, \text{otherwise} \end{cases}$
	A_i^v	$\begin{cases} 1, \text{node } i \text{ is assigned to the } v^{\text{th}} \text{ vehicle} \\ 0, \text{otherwise} \end{cases}$

Target Functions

$$\min \sum_{v=1}^V \sum_{j=1}^n \sum_{k=1}^K x_{0jk}^v \quad (3.1)$$

$$\min \sum_{v=1}^V \sum_{i=0}^n \sum_{j=1}^n t_{ij}^v \quad (3.2)$$

Constraint Functions

$$\sum_{v=1}^V \sum_{i=0}^n x_{ij}^v = 1 \quad \forall i = 1, 2, \dots, n \quad (3.3)$$

$$\sum_{v=1}^V \sum_{j=1}^n x_{ij}^v = 1 \quad \forall i = 1, 2, \dots, n \quad (3.4)$$

$$\forall v = 1, 2, \dots, V$$

$$\forall u = 1, 2, \dots, n$$

$$\sum_{i=0}^n x_{iu}^v - \sum_{j=1}^n x_{uj}^v = 0 \quad (3.5)$$

$$\sum_{j=1}^n \sum_{i=0}^n \sum_{k=1}^K x_{ijk}^v \times q_i \leq Q_k \quad (3.6)$$

$$\forall v = 1, 2, \dots, V$$

$$\sum_{j=1}^n \sum_{i=0}^n \sum_{k=1}^K x_{ijk}^v \times q_i \leq CQ_i$$

$$\forall v = 1, 2, \dots, v$$
(3.7)

$$\sum_{j=1}^n x_{0j}^v \leq 1$$

$$\forall v = 1, 2, \dots, v$$
(3.8)

$$\sum_{i=1}^n x_{i0}^v = 0$$

$$\forall v = 1, 2, \dots, v$$
(3.9)

$$b_i^v \geq L_i - \text{Max}(1 - A_i^v)$$

$$\forall i \in N, \forall v \in V$$
(3.10)

$$a_i^v \leq U_i + \text{Max}(1 - A_i^v)$$

$$\forall i \in N, \forall v \in V$$
(3.11)

$$b_i^v \geq a_i^v + s_i^v - \text{Max}(1 - A_i^v)$$

$$\forall i \in N, \forall v \in V$$
(3.12)

$$a_i^v \geq b_i^v + t_{ij}^v - \text{Max}(1 - x_{ij}^v)$$

$$\forall i \in N, \forall j \in N, \forall v \in V$$
(3.13)

$$a_i^v + s_i^v \leq U_i$$

$$\forall i \in N, \forall v \in V$$
(3.14)

Function Description

(3.1)	Target function 1 minimizes the total number of vehicles.
(3.2)	Target function 2 minimizes the total amount of time.
(3.3), (3.4)	Indicating that each demand point can be serviced by only one taxi, which after completing its services can leave directly and need not return to its starting location.
(3.5)	Indicating that the flow rate at each demand point stays constant.
(3.6)	Indicating that the total number of demand points in each route cannot exceed the upper occupancy limit of a taxi of vehicle type k .
(3.7)	Indicating that the total number of demand points in each route cannot exceed the number of passengers to share a vehicle with that is acceptable to the i^{th} passenger.
(3.8), (3.9)	Indicating that each vehicle leaves immediately and will not return to its starting location, after completing its services.
(3.10)	To ensure that the time at which the v^{th} taxi departs from node i exceeds the upper limit of the time window at node i , with Max being a positive integer maximum.
(3.11)	To ensure that the time at which the v^{th} taxi arrives at node i does not exceed the lower limit of the time window at node i , with Max being a positive integer maximum.
(3.12)	To ensure that the time at which the v^{th} taxi departs from node i exceeds the time at which the k^{th} taxi arrives at node i and the time at which the k^{th} taxi begins services.
(3.13)	To ensure that the time at which the v^{th} taxi arrives at node i exceeds the time at which the k^{th} taxi departs from node i and the time it takes for the k^{th} taxi to travel from node i to node j
(3.14)	To set the range of the service time of the v^{th} taxi at node i

Practical System Operation and Case Analysis

To ensure that, the route planning algorithm of the APP in this study can find the optimal route, which features the smallest total number of vehicles and the shortest driving time, system simulation experiments were carried out at “different scales” and with “different percentages of passengers willing to share vehicles with others”. The goal was to minimize the number of vehicles and achieve the shortest total travel time. At the scale of 50 passengers, 30 random experiments were conducted, each with the percentages of passengers willing to share vehicles with others being 0%, 25%, 50%, 75%, and 100%. The NSGA-II algorithm was used to obtain the optimal solutions, and single-factor analysis of variance (ANOVA), to determine whether an increase in the level of vehicle-sharing willingness has a significant effect on attaining the objective of this study with the vehicle-sharing passenger matching and route planning system.

As shown in Table 2, the case scale of this study was set at 50 passengers, and the percentages of passengers willing to share vehicles with others were set at 0%, 25%, 50%, 75%, and 100%. The matching of vehicle-sharing passengers and the route planning were performed without violating the condition that passengers’ time windows as well as the limitation on the number of passengers sharing a vehicle must be respected. The longitudes and latitudes of passenger demand points were generated randomly.

Table 2: Case Scale

Scale	50 Passengers
Percentage of passengers willing to share vehicles with others	0%
	25%
	50%
	75%
	100%
Number of experiments	50

The results of 50 random experiments were plotted as Figure 1 and Figure 2.

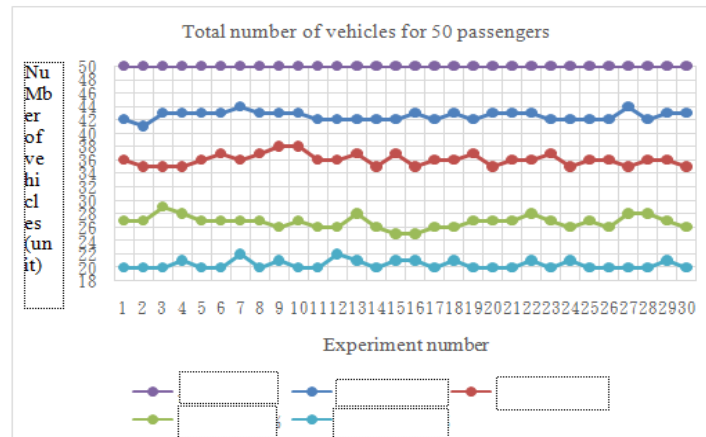


Figure 1: Broken line Graph of Total Number of Vehicles for 50 Passengers, with Different Percentages of Passengers Willing to Share Vehicles with Others

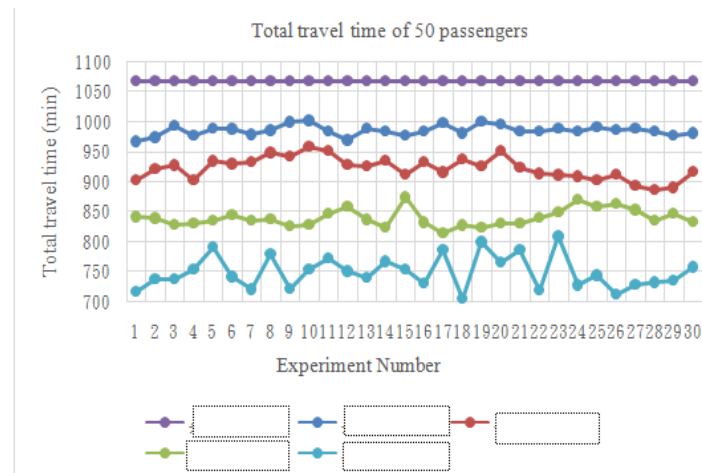


Figure 2: Broken Line Graph of Total Travel Time of 50 Passengers, with Different Percentages of Passengers Willing to Share Vehicles with Others

The experiment results show that, given different levels of vehicle-sharing willingness, higher levels of willingness tend to reduce the number of vehicles and the travel time more. Besides, according to the results of ANOVA, with $\alpha = 0.05$, the p-value of significance = 0.00 ($< \alpha = 0.05$), meaning there are significant differences in the total numbers of vehicles and in the total travel time at the same passenger scale and with different levels of willingness to share vehicles.

CONCLUSION AND SUGGESTIONS

To effectively promote vehicle sharing services, these services must be able to save the time cost of vehicles while

reducing traffic congestion. This study proposes an iOS-based vehicle-sharing passenger matching service system APP that integrates both vehicle information and passenger information. The APP can connect to a rear-end database, through a mobile network to enable rapid data transmission, compilation, and computation. The APP takes advantage of the GPS function of mobile devices, competes with the NSGA-II algorithm, and presents the planned routes via maps built in iOS, so that system users can transmit and receive information in real time. This study has the following achievements:

- The establishment of an APP system: The APP in this study has a front-end user interface created with Xcode, stores data in a MySQL database, and ensures connection between the user interface and the database. Operation of the APP system begins by computing passengers' demands, in order to match passengers. Once a route is planned, the cloud computing results and other related data are sent back to passengers' mobile devices through mobile networks in order to show the route in an iOS map, along with other related information.
- The matching of vehicle-sharing passengers and the planning of routes: This study aims to achieve the smallest number of vehicles and the shortest travel time, by computing with a heuristic algorithm without violating passenger-imposed constraints. To start with, passengers are matched to shorten their waiting time. Then, a route is planned for the passengers in a multipoint-to-multipoint manner. Experiment results show a significant reduction in the number of vehicles needed for vehicle sharing services and in travel time.

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